The use of agricultural resources for global food supply

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Chapter 6.
Future global use of resources for food: the huge impact of regional diets*

Abstract

The global use of resources for food is large, it causes strong environmental problems, and future dietary changes are expected to increase their use. A global trend exists in which diets change to an affluent consumption with the increase of socioeconomic development following the Nutrition Transition Theory. However, it is questionable whether all regions will follow the same food pattern with the present regional cultural differences. In this paper, we do a global analysis of the regional dietary changes from 1960 to 2010 to assess future dietary paths and its impact on the use of agricultural resources. We show that regional dietary trends are stronger than the global trend. So, we expect that future diets will follow present regional dietary compositions. The change to an affluent diet with these regional dietary paths can result in a different use of resources. We show that for the consumption of animal products, the use of resources can be doubled depending on the type of meat. Also, vegetarian diets with large consumption of dairy products can use similar amount of resources than diets with large consumption of meat, depending on the type of meat. Our results give new insight to reduce resource use from a demand perspective, though cultural barriers can be a strong challenge in some regions.

6.1 Introduction

Global food production uses large amounts of resources mainly land, energy and water (FAO, 2013a; FAO, 2013c; Woods et al., 2010). The per capita use of resources is widely different throughout the world, and affluent diets rich in

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animal products use more resources than staple diets (Kastner et al., 2012; Leach et al., 2012; Mekonnen & Hoekstra, 2011a). Diets have changed due to different factors e.g. socioeconomic development, income and urbanization among others. Large changes in dietary patterns are expected in the coming decades especially in developing countries (Alexandratos & Bruinsma, 2012; Godfray et al., 2010a). These changes in diets will have major impact on the increase demand of resources and, therefore, strong environmental impacts (Godfray et al., 2010b; Smil, 2002b; Tilman et al., 2011).

The most recognized global trend of dietary changes in the literature is formulated in the Nutrition Transition theory (Popkin, 1993). This theory states that diets change with socioeconomic development as follows: starting with an under nutrition state, first the amount of calories increase including mainly staple food, then it diversifies increasing the consumption of fats (e.g. animal products), sugars and processed food, and finally reaching a final state by increasing the consumption of fruits, vegetables and carbohydrates, and reducing fats. Since the last decades, these changes in diets have happened faster due to the globalization of the food system and the fast urbanization in many developing countries (Kearney, 2010). So, it is expected that diets in developing countries undergoing fast economic development and urbanization will change rapidly in the future following this pattern (Alexandratos & Bruinsma, 2012; Kearney, 2010).

Most of the studies calculating future use of resources due to dietary changes assume a linear relation between economic development (GDP) and caloric intake in accordance with the nutrition transition (Tilman et al., 2011). In these cases, the saturation level (last phase of the nutrition transition) is achieved similarly to the regions currently in this phase (e.g. Western Europe and North America). However, it is questionable if diets on a global scale will all follow this same food pattern since food consumption is also influenced by culture and religion. Alexandratos & Bruinsma (2012) discuss the regional differences in dietary composition and they show that large diversity exists among countries in the composition of the diets even though some global trends are clear. For example, the clearest global trend in the last decades has been in developing countries towards an increase consumption of livestock products and vegetables oils, but countries like China and Brazil (which account to 1.5 billion people) show a much higher meat consumption for their development stage, and in contrast, India (which account to more than 1 billion people) hardly changed its diet with a very low consumption of meat for a similar increase in economic development. So, regions can strongly deviate from global dietary trends.

In this paper, we study the global changes in diets associated with their use of resources. We study the regional dietary changes in the past to assess future regional dietary changes. To do this, the paper is divided into two parts. First, we study the development of diets to assess future dietary changes. In this part of the paper, our main research questions are: What is the major trend of dietary changes? Is the global dietary trend or the regional dietary trend stronger? What can we expect for future changes in diets? To answer these questions we study the differences in food composition among regions. In the second part of the paper, we study the use of resources for these future dietary paths. In this section, our main research question is: What is the impact on the use of resources of the regional differences in food composition?

6.2 Methodology

We divided the world into 13 regions to discuss the global differences in diets and the use of resources. We grouped the regions defined by the FAO as follows: E-M-W Africa (including East, Middle and West Africa), N Africa (North Africa), S Africa (South Africa), China, India, S-E Asia (South, East and Southeast Asia), W-C Asia (West and Central Asia), C-S America (Central and South America and the Caribbean), E Europe (Eastern Europe), N America (North America), W-N Europe (West and North Europe) and Oceania. China and India are one region each because of their large population. Appendix 6 shows the countries included in each region.

General approach to calculate the use of resources per person

The amount of resources needed to produce the food of a person depends on how the food was produced: the agricultural technology, and on what people eat: the type of diet. Several studies have calculated the use of resources per person (Kastner et al., 2012; Leach et al., 2012; Mekonnen & Hoekstra, 2011a), what some call “footprint” of food. They show large differences among regions due to both differences in agricultural production systems and type of diets. They show that, in general, affluent diets rich in animal products require more resources than staple diets because the production of a kilogram of animal product requires more resources than a kilogram of vegetable products (Berners-Lee et al., 2012; González et al., 2011; Mekonnen & Hoekstra, 2012; Mekonnen & Hoekstra, 2011b; Pierer et al., 2014).

However, in some cases the differences in agricultural production systems can overrule the differences in diets. Kastner et al. (2012) show that regions with affluent diets including large consumption of animal products (e.g. Western Europe) require similar amounts of land than regions with very basic staple diets with low consumption of animal products (e.g. Middle Africa) due to the differences in agricultural technologies, the former with high land efficient systems (high crop yields), and the latter with low land efficient systems (low crop yields). So, with the footprint studies it is not possible to identify the impact of only the global differences in diets. In contrast with these studies, we aim to discuss only the differences in diets to identify the impact of different dietary changes.

In addition, the type of diet is not only related with the amount of food consumed, but also with the type of food consumed. So, the type of diet depends on the amount of caloric intake as well as on the food composition of the diet. Since we only focus on the impact of the differences in diets, we keep the technology factor constant. By doing so, we can identify the impact of global differences of both the amount of food consumed and the type of food consumed (food composition of the diet).

To keep the technology factor constant, we use one production system to calculate the use of resources per capita representing a global average production system or a production system of a specific country when the global data is not available. The data was gathered from several sources and table 6.1 shows the data that we used. All data was gathered from the literature except for the use of land for the vegetable products for which we used the inverse value of the crop yield of the global average in the year 2010 given by the FAOSTAT (FAO, 2013b). The country level data for the animal products was gathered from de Vries & de Boer (2010). They collected production data from several countries and production systems in Europe and discuss their differences. We use their high estimates for each animal food product.

Table 6.1. Data for the use of agricultural resource per amount of food.
Sources: [1] Crop yields from FAOSTAT (FAO, 2013b);
[2] Mekonnen & Hoekstra (2011b); [3] de Vries & de Boer (2010)

Vegetable Products									
Resource	Region	Unit	cereals	roots	pulses	veg oils	sugars	vegetables	fruits
Land[1]	world avg	m^2/kg food	2.8	0.7	11.2	10.2	1.7	0.5	0.9
Water[2]	world avg	m^3/ton food	1 644	387	4 055	4 190	1 666	322	967

Animal Products							
Resource	Region	Unit	milk	eggs	bovine	poultry	pork
Land[3]	Europe	m^2/kg food	2	6	31	9	11
		m^2/kg protein	59	48	258	52	64
Water[2]	World avg	m^3/ton food	1020	3265	15415	4325	5988
		m^3/kg protein	31	29	112	34	57
Energy[3]	Europe	MJ/kg protein	68	95	273	96	129
GHG[3]	Europe	kg CO2-e/kg food	1	5	32	7	10
		kg CO2-e/kg protein	38	38	170	36	53

We combined data of resource use with data of food consumption per person. The food consumption data include around 100 food items depending on the country (FAO, 2013d). We grouped the food items into food categories to identify the relevant differences of the use of resources. We used seven food categories for the vegetable products: cereals, roots, pulses, vegetable oils, sugars, vegetables and fruits. Within each food category, the use of resources of the food items is very similar due to the physiology of the crops. For example, for cereals, the global average of land use to produce a kg of wheat, rice and maize is 3.3 m^2, 2.3 m^2 and 2 m^2 respectively; in contrast, for root is much lower, to produce a kg of potatoes and cassava is 0.6 m^2 and 0.8 m^2 respectively (we calculated these values from crop yield data of 2010 from FAOSTAT (FAO, 2013b)). So, we grouped the staple food items into three categories which show relative differences among them: cereals, roots and pulses. For the animal products, a more detailed analysis is needed so we grouped the food items into 7 food categories: milk (excluding butter), eggs, bovine meat, poultry meat, pork meat, fish and animal fats (though no data of resource use is available for animal fats and fish). We did not group all the meat products into one category because of the differences in the use of resources among them (see table 6.1). For example, bovine meat requires three times more land to produce a kilogram of meat than poultry and pork meat.

For the use of energy and GHG emissions, no data is available for vegetable food categories. Some studies have calculated the country level data of the use of energy and GHG emissions for specific vegetable food items (Berners-Lee et al., 2012; González et al., 2011). They show large differences among specific food products produced in Europe, e.g. tomatoes produced in heated greenhouses in the United Kingdom require 130 MJ/kg and tomatoes produced in the open field in Spain require only 3 MJ/kg (González et al., 2011). With these large differences within one food item, it is not possible to group the specific vegetables into one category. So for energy use and GHG emissions, we only analysed the animal products.

Table 6.1 provides an overview of the use of resources for food. Large variation exists in resource use between food categories. For vegetable products, pulses and vegetable oils are the most resource intensive per kilogram of food, then cereals, and fruits, roots and vegetables are the lowest. The animal products in general are more resource intensive, and differences exist among the food categories. Beef is the most resource intensive per kilogram of food, and milk is the lowest. However, in some cases some vegetable products require more resources than animal products. For example, the production of a kilogram of pulses requires more land than the production of a kilogram of poultry meat or pork meat. The explanation can be found in the data that we used. The data for animal products refer to a production system of Europe and the data for the vegetable products refer to the global average. The European production system is an intensive system and resource efficient in comparison with other production systems in the world. As a result, with the data that we used, the animal products are produced in more efficient systems in comparison with the vegetable products. The animals in these systems are fed with grains produced with high yields which use less land per kilogram of feed. Elferink & Nonhebel (2007, fig 2) show that pork, chicken or beef meat produced with feed from high yield systems requires half of the land than meat produced with feed from global average crop yield. This means that by using the data of table 6.1, we are showing an underestimation in land use for animal products in respect to the average global production systems.

The units of table 6.1 are in amount of resources per kilogram of food and per kilogram of protein which are the units commonly used in studies of resource use for food. Studies of food consumption patterns commonly use units of calories or proteins per person per day to discuss diets. So, proteins are the common ground unit to combine resource use data and food consumption data. In section 4.2, we calculate the use of resources for the whole diet: the vegetable products and the animal products, since no data of proteins is available for the vegetable products, then we use the data of resources per kilogram of food and combined it with consumption data in kilogram per person per year. In section 4.2, we only calculate the use of resources for animal products. Then, we can use the data of resources per kilogram of protein and combine it with consumption data in protein per person per day.

Food consumption data

We discuss the differences in diets using country level food supply data of the Food Balance Sheets of the FAO (FAO, 2013d). We use data of kcal/cap/day which are the units most commonly used to describe food consumption. We aggregated the daily caloric supply per capita of all countries in each region to obtain the average caloric supply of the region. We included 14 food categories, the 12 food categories included in table 6.1 and fish and animal fats which are relatively relevant for the diets of some regions. We discuss the changes in the last five decades for which we used data of 1961 to discuss the year 1960, and data of 2009 to discuss the year 2010.

The food supply data is not the actual diet of the population since it includes food losses throughout the food chain. These food losses are different among regions. For example, for developing countries the food losses are mainly on-farm and during transport and food processing, and in developed countries the food losses are mainly in the retail and food service and at home (Godfray et al., 2010a). A more accurate source of data would be to use household level surveys. Unfortunately, these surveys are only on a country level, and not for a global level. However, Gerbens-Leenes et al. (2010, fig7) shows a clear relation between food supply data and household level surveys. For this reason, throughout the paper, we refer to diets when using food supply data.

Differences in dietary composition

We calculated mathematically the differences in dietary composition among regions and compared it with the change in time in dietary composition for each region to show whether the global or regional dietary trend is stronger. To do this, we used the equation of Euclidean distance between two points:

$$d(p,q) = \sqrt{\sum_{i=1}^{k}(q_i - p_i)^2}$$

where p and q are two dietary composition of figure 6.2 and k is the number of dimension of these points which in our case are the food categories, seven for both the vegetable products and the animal products. The distance gives an indication of the differences between the dietary composition p and q and we use it for comparison. First, we calculated the differences in time. So the change in dietary composition from 1960 to 2010 for every region using:

$$\Delta t(p) = d(p_{t1}, p_{t2}) = \sqrt{\sum_k (p_{t1} - p_{t2})^2} \qquad \text{eq. 1}$$

where p is the region, $p_{t1}$is the dietary composition in 1960, p_{t2} is the dietary composition in 2010, and k are the food categories. Then, we calculated the difference among regions for each year, 1960 and 2010, using the following equation:

$$d_{ij}(p_i, q_j) = \sqrt{\sum_k (p_{ik} - q_{jk})^2} \qquad \text{eq. 2}$$

where p and q are the dietary composition of regions i and j in the same year, and k are the food categories. With equation 1, we obtain a vector Δt_i which indicate the change from 1960 to 2010, and with equation 2 we obtain a symmetric matrix d_{ij} indicating the differences among regions.

6.3 Global and regional dietary paths: what can we expect for future regional diets?

In this section, we evaluate the regional changes in diets in the period of 1960 to 2010 to assess future developments in diets. The changes have been driven by two trends: the global dietary trend (following the nutrition transition theory) and the specific-regional trends (following the regional food patterns). Both trends have been discussed by Alexandratos & Bruinsma (2012). Most developed countries have reached a saturated level (last phase of the nutrition transition) and diets have been relatively stable; in contrast, developing countries have changed fast in the last decades by a shift towards livestock products and vegetable oils. This reflects the global trend. But, as mentioned before, the countries also show country-specific deviations of this trend. For example, the increase of meat consumption in China and Brazil was faster than in other developing countries, and in India it was much more slower for a similar economic development stage (Alexandratos & Bruinsma, 2012). We study the regional and global trends to find out which has been stronger.

Figure 6.1 shows the daily caloric intake of each region in 1960 and in 2010 for both vegetable and animal products for the 13 regions and the global average. This figure shows that regions largely differ from the global average and among each other. Also, large changes in diets have occurred during this period, and each region changed differently. The changes have been in both total caloric consumption and in food composition. To identify the dietary paths we look only at the food composition of the diets which is illustrated in figure 6.2. Note that the numbers in figure 6.2 are relative and the difference in total caloric consumption among regions and among the years 1960 and 2010 can be strong. For instance, the caloric consumption of animal products in E-M-W Africa is less than 200 kcal/cap/day and in N America is 1000 kcal/cap/day. And, the caloric consumption of animal products in China in 1960 is less than 100 kcal/cap/day and in 2010 is more than 600 kcal/cap/day.

In one hand, to identify the regional dietary path we need to compare the dietary composition of 1960 and 2010 for each region using figure 6.2. If the dietary composition in both years remains the same, then it means that it followed its regional path, even if the amount of calories changed. The consumption of animal products in China is a good example for which the caloric consumption increased 12 times (figure 6.1), but the composition is relatively similar in both years mainly with pork and eggs (figure 6.2).

In the other hand, to identify the global dietary path, we need to compare the dietary compositions among the regions. If the dietary compositions are becoming more similar among each other, it means that regions are changing towards a global food patterns. This is more difficult to identify just by looking at figure 6.2, so we use equation 1 and 2 to quantify the differences and identify which trend is stronger. But before these calculations, we discuss three global trends and the deviations among the regions.

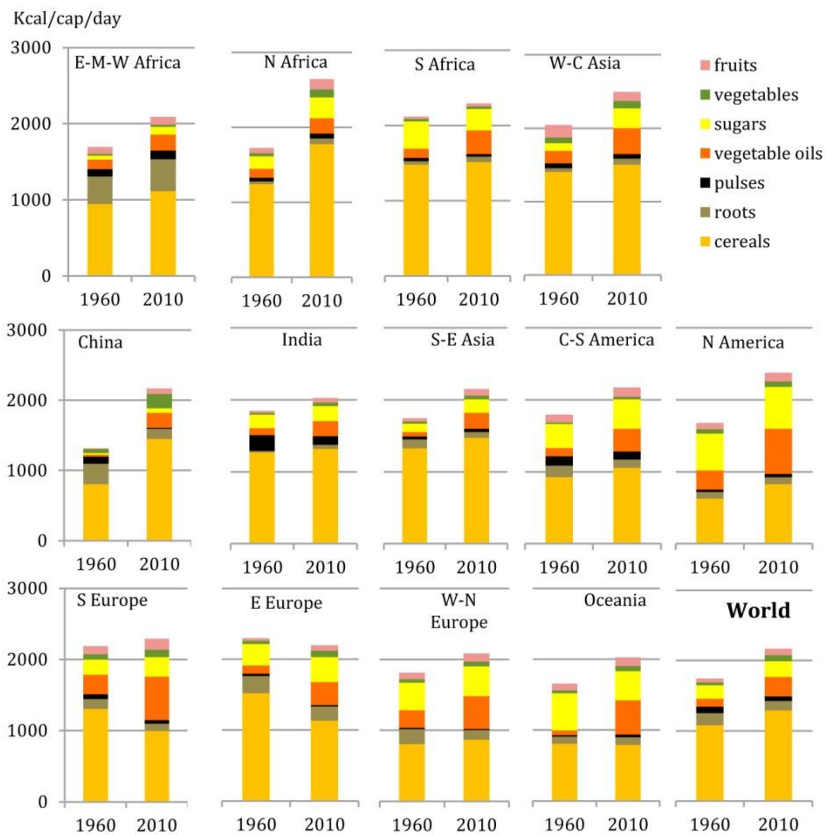

Figure 6.1 Global differences in diets. The graphs show the daily caloric intake in kcal/cap/day of the vegetable products and the animal products (next page) in 1960 and 2010. See text for details.

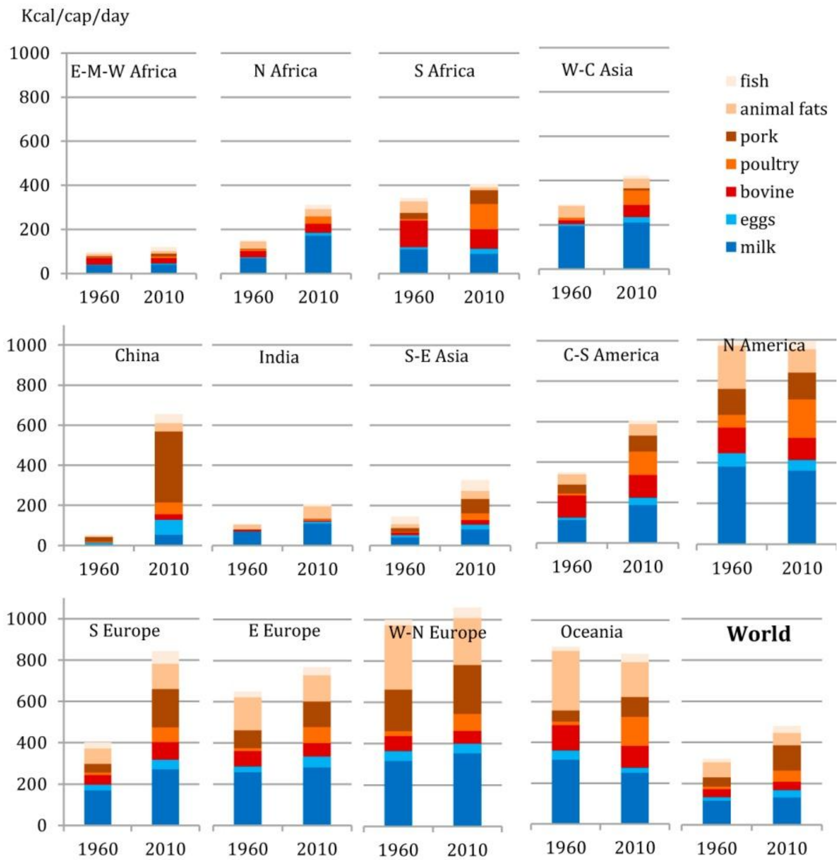

Figure 6.1 *(continue)* Global differences in diets.

First, a global trend during this period was the reduction in the per capita consumption of staple food (roots, pulses and cereals). However, regions changed differently and the share of this staple food in their diet is relatively similar in 1960 and in 2010 (figure 6.2). The large cereals' consumers, N Africa, S Africa and S-E Asia, are still relative large consumers compared with the other regions. E-M-W Africa, E Europe and China are relative large consumer of roots. They all changed differently during this period, China even decreased, but they all remained large consumers in relation to the other regions. India and C-S America are the largest consumers of pulses, and even though they decreased their consumption, they are still the relative largest consumers.

Second, the global per capita consumption of affluent vegetable products (vegetable oils, vegetables, sugars and fruits) increased. The largest global increase in the per capita consumption was for vegetable oils and vegetables which doubled, fruits increased 70% and sugars "only" 20% (FAO, 2013d). Each region did not increase the consumption of all four products in the same way; and, again, the share of these food items in the diet is similar in both years as follows (figure 6.2). Looking at sugars and vegetable oils, N Africa, E Europe, America and Oceania show a larger consumption of sugars than vegetable oils; in contrast, E-M-W Africa, China and S Europe show a larger consumption of vegetable oils than sugars. In the same way for fruits and vegetables, Africa, America and S-E and W-C Asia have a larger consumption of fruits than vegetables; in contrast, China and E Europe have a larger consumption of vegetables than fruits.

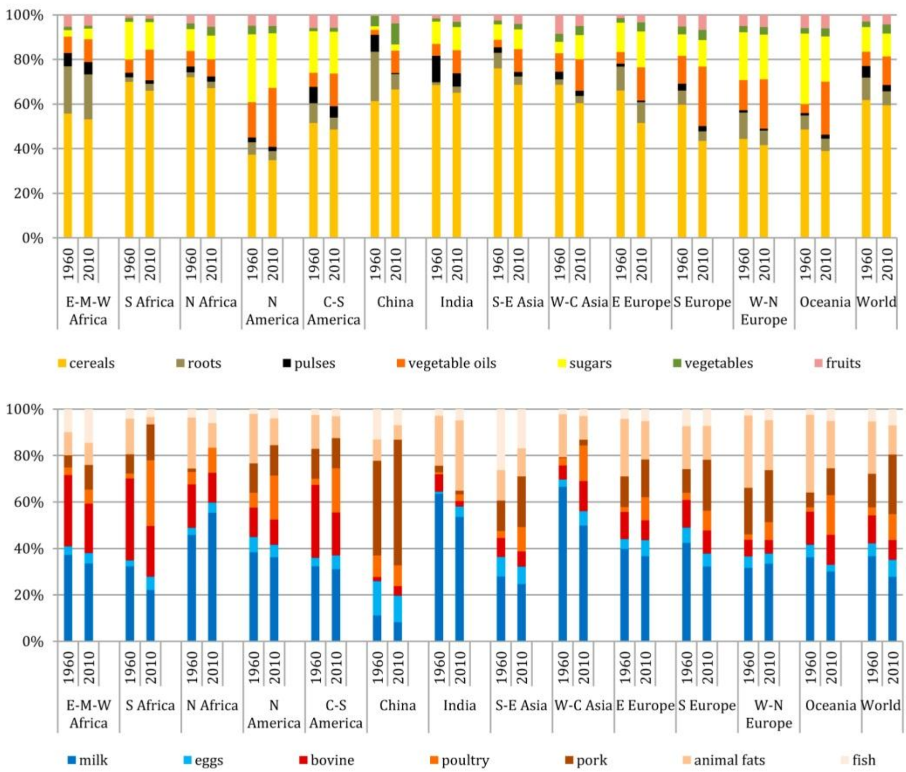

Figure 6.2 Regional differences in dietary composition. The graphs show the food composition of the daily caloric intake of the vegetable products (top) and the animal products (bottom) in 1960 and in 2010.

Third, the consumption of animal products became more diversified (figure 6.2). In general, the consumption of poultry meat increased in all regions, strongly in S Africa, America, S-E and C-W Asia and Oceania, but still the change was different following their dietary composition. N Africa, India and W-C Asia are the relative largest consumers of milk for which milk accounts to more than half of their animal products calories, even though the per capita consumption of milk in other regions is larger: N America and W-N Europe. All Africa and America are the relative largest beef consumers. Even though in some regions (S Africa and all America) poultry meat replaced part of the beef consumption during this period. China is by far the largest consumer of pork, but also Europe and S-E Asia are relative large consumers. The largest consumers of animal fats are India, all Europe and Oceania. Finally, S-E Asia and E-M-W Africa are the relative largest fish consumers.

Table 6.2 Differences in dietary composition

These tables show the results of equations 1 and 2 based on the data of figure 6.2.

6.2a.Change in time (Δt) and differences among regions (d_{ij}).

The first row for vegetable and animal products shows the average values of vector Δt and matrix d_{ij}, in 1960 and in 2010. The following rows show the values of vector Δt, and the average distance of each region in relation to the other regions (avg d_{ij}). The complete matrix d_{ij} is shown in table 6.2b where the avg d_{ij} is shown in the last column. See text for details.

Vegetable products				Animal products			
		1960	2010			1960	2010
Average values:	$\lvert \Delta t \rvert$ = 0.13	$\lvert d_{ij} \rvert$ = 0.23	$\lvert d_{ij} \rvert$ = 0.21	Average values:	$\lvert \Delta t \rvert$ = 0.18	$\lvert d_{ij} \rvert$ = 0.30	$\lvert d_{ij} \rvert$ = 0.29
	Δt	Avg.d_{ij}	Avg. . d_{ij}		Δt	Avg. . d_{ij}	Avg. . d_{ij}
E-M-W Africa	0,04	0,24	0,24	E-M-W Africa	0,13	0,29	0,26
S Africa	0,10	0,20	0,18	S Africa	0,34	0,30	0,33
N Africa	0,05	0,20	0,20	N Africa	0,17	0,25	0,33
N America	0,12	0,31	0,25	N America	0,16	0,20	0,20
C-S America	0,10	0,20	0,18	C-S America	0,22	0,28	0,23
China	0,20	0,26	0,23	China	0,16	0,52	0,54
India	0,09	0,21	0,18	India	0,15	0,34	0,38
S-E Asia	0,11	0,23	0,20	S-E Asia	0,15	0,34	0,27
W-C Asia	0,12	0,21	0,16	W-C Asia	0,24	0,37	0,29
E Europe	0,18	0,18	0,17	E Europe	0,13	0,22	0,21
S Europe	0,22	0,18	0,22	S Europe	0,17	0,22	0,22
W-N Europe	0,11	0,25	0,21	W-N Europe	0,12	0,29	0,24
Oceania	0,25	0,28	0,23	Oceania	0,22	0,26	0,23

Table 6.2 (continue)

6.2b. Detail differences among regions: matrix d_{ij}

Vegetable products

t=1960 |dij|=0.23	E-M-W Africa	S Africa	N Africa	N America	C-S America	China	India	S-E Asia	W-C Asia	E Europe	S Europe	W-N Europe	Oceania	**Avg**
E-M-W Africa	0	0,28	0,26	0,38	0,21	0,10	0,26	0,26	0,23	0,19	0,18	0,25	0,34	**0,24**
S Africa	0,28	0	0,08	0,37	0,21	0,28	0,12	0,13	0,14	0,10	0,15	0,29	0,27	**0,20**
N Africa	0,26	0,08	0	0,42	0,24	0,25	0,10	0,08	0,08	0,11	0,14	0,32	0,33	**0,20**
N America	0,38	0,37	0,42	0	0,22	0,44	0,40	0,47	0,41	0,36	0,31	0,13	0,16	**0,31**
C-S America	0,21	0,21	0,24	0,22	0	0,25	0,21	0,28	0,23	0,17	0,15	0,13	0,15	**0,20**
China	0,10	0,28	0,25	0,44	0,25	0	0,24	0,23	0,24	0,19	0,21	0,31	0,37	**0,26**
India	0,26	0,12	0,10	0,40	0,21	0,24	0	0,14	0,13	0,15	0,16	0,32	0,32	**0,21**
S-E Asia	0,26	0,13	0,08	0,47	0,28	0,23	0,14	0	0,12	0,12	0,19	0,37	0,37	**0,23**
W-C Asia	0,23	0,14	0,08	0,41	0,23	0,24	0,13	0,12	0	0,14	0,12	0,31	0,34	**0,21**
E Europe	0,19	0,10	0,11	0,36	0,17	0,19	0,15	0,12	0,14	0	0,12	0,25	0,26	**0,18**
S Europe	0,18	0,15	0,14	0,31	0,15	0,21	0,16	0,19	0,12	0,12	0	0,20	0,26	**0,18**
W-N Europe	0,25	0,29	0,32	0,13	0,13	0,31	0,32	0,37	0,31	0,25	0,20	0	0,15	**0,25**
Oceania	0,34	0,27	0,33	0,16	0,15	0,37	0,32	0,37	0,34	0,26	0,26	0,15	0	**0,28**

t=2010 |dij|=0.21	E-M-W Africa	S Africa	N Africa	N America	C-S America	China	India	S-E Asia	W-C Asia	E Europe	S Europe	W-N Europe	Oceania	**Avg**
E-M-W Africa	0	0,23	0,23	0,36	0,21	0,21	0,22	0,23	0,20	0,17	0,26	0,27	0,29	**0,24**
S Africa	0,23	0	0,08	0,36	0,19	0,14	0,06	0,06	0,07	0,16	0,27	0,27	0,30	**0,18**
N Africa	0,23	0,08	0	0,40	0,22	0,11	0,06	0,04	0,09	0,19	0,30	0,31	0,34	**0,20**
N America	0,36	0,36	0,40	0	0,19	0,42	0,37	0,41	0,31	0,23	0,15	0,10	0,07	**0,25**
C-S America	0,21	0,19	0,22	0,19	0	0,26	0,19	0,23	0,15	0,08	0,15	0,11	0,14	**0,18**
China	0,21	0,14	0,11	0,42	0,26	0	0,12	0,10	0,13	0,21	0,31	0,33	0,36	**0,23**
India	0,22	0,06	0,06	0,37	0,19	0,12	0	0,06	0,07	0,17	0,28	0,29	0,31	**0,18**
S-E Asia	0,23	0,06	0,04	0,41	0,23	0,10	0,06	0	0,10	0,20	0,30	0,32	0,35	**0,20**
W-C Asia	0,20	0,07	0,09	0,31	0,15	0,13	0,07	0,10	0	0,12	0,21	0,23	0,25	**0,16**
E Europe	0,17	0,16	0,19	0,23	0,08	0,21	0,17	0,20	0,12	0	0,16	0,13	0,17	**0,17**
S Europe	0,26	0,27	0,30	0,15	0,15	0,31	0,28	0,30	0,21	0,16	0	0,10	0,10	**0,22**
W-N Europe	0,27	0,27	0,31	0,10	0,11	0,33	0,29	0,32	0,23	0,13	0,10	0	0,03	**0,21**
Oceania	0,29	0,30	0,34	0,07	0,14	0,36	0,31	0,35	0,25	0,17	0,10	0,03	0	**0,23**

Animal products

t=1960 |dij|=0.30	E-M-W Africa	S Africa	N Africa	N America	C-S America	China	India	S-E Asia	W-C Asia	E Europe	S Europe	W-N Europe	Oceania	**Avg**
E-M-W Africa	0	0,11	0,21	0,24	0,13	0,54	0,38	0,31	0,40	0,26	0,22	0,36	0,30	**0,29**
S Africa	0,11	0	0,24	0,25	0,06	0,54	0,43	0,36	0,46	0,27	0,26	0,34	0,28	**0,30**
N Africa	0,21	0,24	0	0,15	0,23	0,59	0,22	0,35	0,25	0,16	0,13	0,28	0,17	**0,25**
N America	0,24	0,25	0,15	0	0,21	0,45	0,29	0,28	0,32	0,07	0,08	0,16	0,15	**0,20**
C-S America	0,13	0,06	0,23	0,21	0	0,49	0,41	0,34	0,44	0,23	0,23	0,30	0,27	**0,28**
China	0,54	0,54	0,59	0,45	0,49	0	0,69	0,37	0,71	0,46	0,47	0,40	0,53	**0,52**
India	0,38	0,43	0,22	0,29	0,41	0,69	0	0,45	0,06	0,27	0,24	0,38	0,31	**0,34**
S-E Asia	0,31	0,36	0,35	0,28	0,34	0,37	0,45	0	0,48	0,28	0,25	0,31	0,34	**0,34**
W-C Asia	0,40	0,46	0,25	0,32	0,44	0,71	0,06	0,48	0	0,31	0,27	0,42	0,35	**0,37**
E Europe	0,26	0,27	0,16	0,07	0,23	0,46	0,27	0,28	0,31	0	0,08	0,13	0,12	**0,22**
S Europe	0,22	0,26	0,13	0,08	0,23	0,47	0,24	0,25	0,27	0,08	0	0,20	0,18	**0,22**
W-N Europe	0,36	0,34	0,28	0,16	0,30	0,40	0,38	0,31	0,42	0,13	0,20	0	0,16	**0,29**
Oceania	0,30	0,28	0,17	0,15	0,27	0,53	0,31	0,34	0,35	0,12	0,18	0,16	0	**0,26**

t=2010 |dij|=0.29	E-M-W Africa	S Africa	N Africa	N America	C-S America	China	India	S-E Asia	W-C Asia	E Europe	S Europe	W-N Europe	Oceania	**Avg**
E-M-W Africa	0	0,29	0,28	0,20	0,18	0,54	0,37	0,21	0,25	0,19	0,18	0,25	0,20	**0,26**
S Africa	0,29	0	0,42	0,22	0,15	0,49	0,54	0,29	0,35	0,30	0,29	0,35	0,24	**0,33**
N Africa	0,28	0,42	0	0,25	0,30	0,73	0,24	0,40	0,08	0,26	0,32	0,34	0,30	**0,33**
N America	0,20	0,22	0,25	0	0,09	0,52	0,33	0,22	0,18	0,11	0,15	0,19	0,12	**0,20**
C-S America	0,18	0,15	0,30	0,09	0	0,51	0,40	0,23	0,23	0,17	0,18	0,23	0,13	**0,23**
China	0,54	0,49	0,73	0,52	0,51	0	0,74	0,38	0,68	0,49	0,42	0,44	0,52	**0,54**
India	0,37	0,54	0,24	0,33	0,40	0,74	0	0,43	0,26	0,28	0,35	0,31	0,33	**0,38**
S-E Asia	0,21	0,29	0,40	0,22	0,23	0,38	0,43	0	0,36	0,18	0,13	0,18	0,21	**0,27**
W-C Asia	0,25	0,35	0,08	0,18	0,23	0,68	0,26	0,36	0	0,21	0,28	0,30	0,24	**0,29**
E Europe	0,19	0,30	0,26	0,11	0,17	0,49	0,28	0,18	0,21	0	0,08	0,10	0,13	**0,21**
S Europe	0,18	0,29	0,32	0,15	0,18	0,42	0,35	0,13	0,28	0,08	0	0,09	0,15	**0,22**
W-N Europe	0,25	0,35	0,34	0,19	0,23	0,44	0,31	0,18	0,30	0,10	0,09	0	0,16	**0,24**
Oceania	0,20	0,24	0,30	0,12	0,13	0,52	0,33	0,21	0,24	0,13	0,15	0,16	0	**0,23**

Now, we use equation 1 and 2 to quantify whether the global or regional dietary trend was stronger during this period. The results are shown in tables 6.2 where d_{ij} shows the differences in dietary composition among regions and Δt shows the change in time in dietary composition for each region. The numbers of these tables do not measure a real value, only show an indication of the differences of dietary composition and we use them for comparison. The largest the number, the largest the difference of dietary composition between two region or throughout the period.

The first row of table 6.2a shows the average of Δt and d_{ij}. For both vegetable and animal products, the average Δt is smaller than d_{ij}. This means that the difference among regions (d_{ij})is larger than the change in time within the regions (Δt). So, in general, the regional trend of dietary pattern is stronger than the global trend, and regions have followed their own dietary composition. The average Δt and d_{ij} show that $|d_{ij}|$ in 1960 was larger than in 2010. This means that in 2010 the dietary composition of the regions are more similar among each other than in 1960 indicating that regions changed towards a more similar food consumption (following the global trend). However, this trend of conversion to a global diet is slow. In the 50 years of study (1960 to 2010) the differences among regions only changed from 0.23 to 0.21 for vegetable products and from 0.30 to 0.29 for animal products. The differences of dietary composition of the animal products is stronger than of the vegetable products suggesting that regional patterns of animal products are stronger or more evident than of vegetable products.

Some regions changed more than others which is indicated in the values of Δt. E-M-W Africa and S Africa changed very little their vegetable products composition: their values (0.04 and 0.5 respectively) are much lower than $|\Delta t|$. In contrast, S Europe and Oceania changed a lot. For animal products, S Africa was the region with the stronger changes, and E-M-W Africa, E Europe and W-N Europe were the regions with the lowest change.

The columns "avg d_{ij}" of table 6.2a indicate the average distance between each region and the rest. This is the average of each row of d_{ij} (see the last columns of table 6.2b). For most regions, the avg d_{ij} is larger than Δt indicating that the difference of that region in comparison with the rest is larger than the change in time. Showing again that for those regions the regional dietary trend was stronger than the global trend. However, for some regions, the change in time in food composition was stronger (see red numbers): the change of vegetable products in E Europe, S Europe and Oceania was stronger than the differences of these region in respect with the rest, and the change in animal products in S Africa was stronger than the difference of this region with the rest.

Thus, from this analysis, we can expect that future changes in diets will follow regional dietary paths if we assume that past trends remain in future. Based on this finding, in the next section we assess the impact of these regional dietary trends on the use of agricultural resources.

6.4 Future use of agricultural resources: will regional differences in dietary composition have an impact?

Large awareness in the literature is focused on the large increase in use of agricultural resources due to future dietary changes. As we have shown, regions are following different dietary paths. In this section, we discuss the impact of the different regional dietary paths on the use of resources. To have a reference with the present situation, first, we discuss the impact of the present diets on the use of resources and then we discuss the impact of future dietary changes.

Impact of present diets

Here, we evaluate the impact of the differences in diets shown in figure 6.1 using the production data of table 6.1. Figure 6.3 shows the use of land, water, energy and GHG emissions for the diets of each region in 2010. The use of land and water shows that the largest difference in resource use is caused by the consumption of animal products, and the use of resources for vegetable products is relatively similar among the regions (see the green bars in figure 6.3). For energy and GHG emissions no data is available for the specific vegetable food categories.

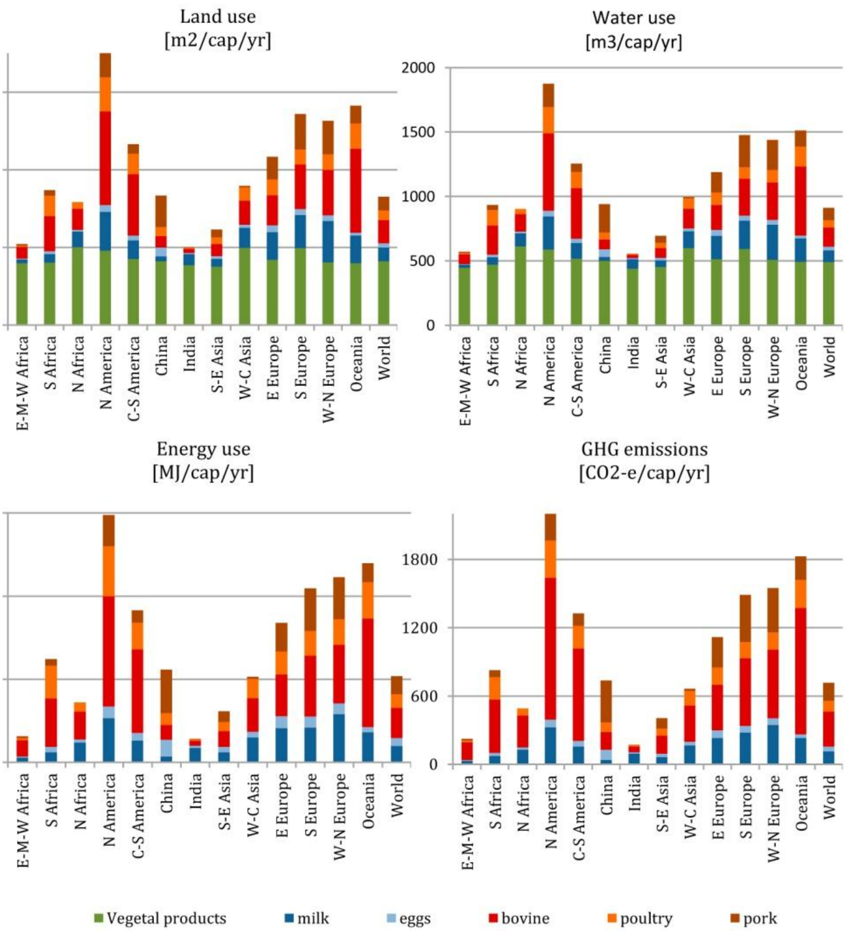

Figure 6.3 Impact of the regional dietary differences on the use of agricultural resources.

The differences in total use of resource per person are enormous. The average diet of N America requires more than three times of land and water than the average diet of E-M-W Africa and India. The animal products consumption per capita of N America requires ten to twelve times more land, water, energy, and emits ten times more GHG than the per capita animal products consumption of E-M-W Africa and India. This huge difference is mainly due to the very low consumption of animal products in E-M-W Africa and India. But, the differences are also large by comparing with a diet with medium consumption of animal products like China and E Europe. A person in N America consumes three times more land, water, energy respectively and emits three times more GHG than a person in China, and two times more than a person in E Europe.

Thus, the largest differences in the use of resources are caused by the strong differences in the consumption of animal products among the regions. These differences are due to both the caloric intake and food composition (the type of animal products), and, as figure 6.1 shows, these differences are enormous. The consumption of animal products is expected to strongly increase specially in developing countries (Alexandratos & Bruinsma. 2012) which currently consume relative small amount of animal products. So, to discuss the impact of resources in future diets, we focus on the consumption of animal products.

Impact of future diets following regional dietary paths

As mentioned before, diets are expected to change in the coming decades especially in developing countries due to the increase of socioeconomic development, globalization of the food system and urbanization. A clear relation has been shown between the increase of income (GDP per capita) and the consumption of animal products (Gerbens-Leenes et al., 2010; Poleman & Thomas, 1995). For income values below US$10,000 per capita, a linear relation has been shown for all countries between the increase of income and the increase consumption of animal products. This relation starts with very low values of income and very low consumption of animal products, and reaches around 1000 kcal/cap/day of animal products with income values of US$10,000 per capita. Then, with higher values of income, the consumption of animal products does not change and the diets are relatively stable. This means, that a saturation level is reached at around 1000 kcal/cap/day of animal products consumption. Most developed countries already show this saturation level (see W-N Europe and N America in figure 6.1) and their diets have been relatively stable.

In the coming decades, developing countries will increase their income and they are expected to follow this trend between income and consumption of animal food products. However, as we have shown in section 3, the type of animal products will be different among the regions in accordance to their current food composition. To evaluate the future impact in resource use due to the different choice of type of animal products, we assume that all regions consume the same amount of animal products: 60 gr of protein/cap/day (which is the saturation level of around 1000 kcal/cap/day) but with the food composition of each region of 2010 (see figure 6.4). We do this to analyse the impact on the use of resources if all region change to an affluent consumption reaching a saturation level similar to the developed countries. We use 60 gr of protein which is the per capita consumption of animal products of the European Union in 2010 (FAO, 2013d), and we assume that this is the saturation level that all region can reach with an increase of income. We use protein consumption instead of caloric consumption because the values of resource use per type of food (table 1) are in amount of resource per kilogram of protein.

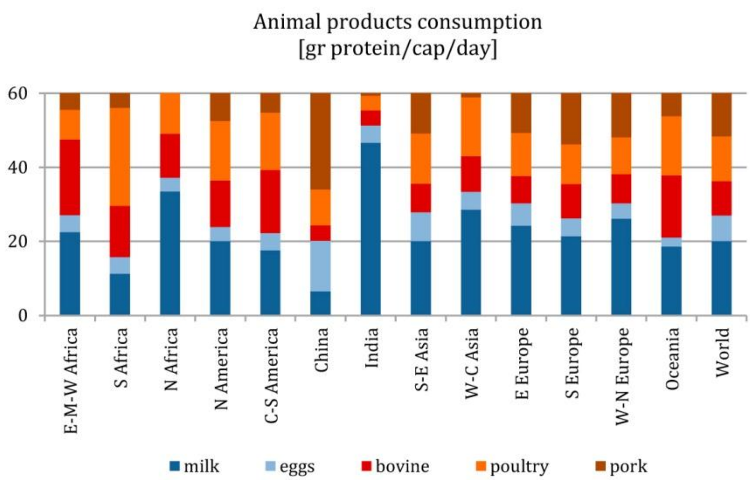

Figure 6.4 Daily consumption of 60 gr/cap/day of animal products with different regional dietary composition. The food composition is based on the values of 2010 of the Food Balance Sheets (FAO, 2013d).

Figure 6.5 shows the use of resources for the consumption of 60 gr of protein/cap/day of animal products. The differences among regions are smaller than the differences shown in figure 6.3, but still are relevant showing the large impact of the choice of the type of animal product in each region. The regions with the largest use of resources: E-M-W Africa, C-S America and Oceania, use 60% to 80% more resources per person than the regions with the lowest use of resources: India and China for the same protein consumption. This is mainly related with the consumption of bovine meat. In general, the share of resources for bovine meat production is large: a lot of red is shown in figure 6.5, even though the share of bovine meat in the protein consumption is not as large: a few red is shown in figure 6.4. This is due to the high requirement of resources per kilogram of protein of bovine meat. As shown in table 6.1, bovine meat requires 3-5 times more resources per kilogram of protein than the other animal products.

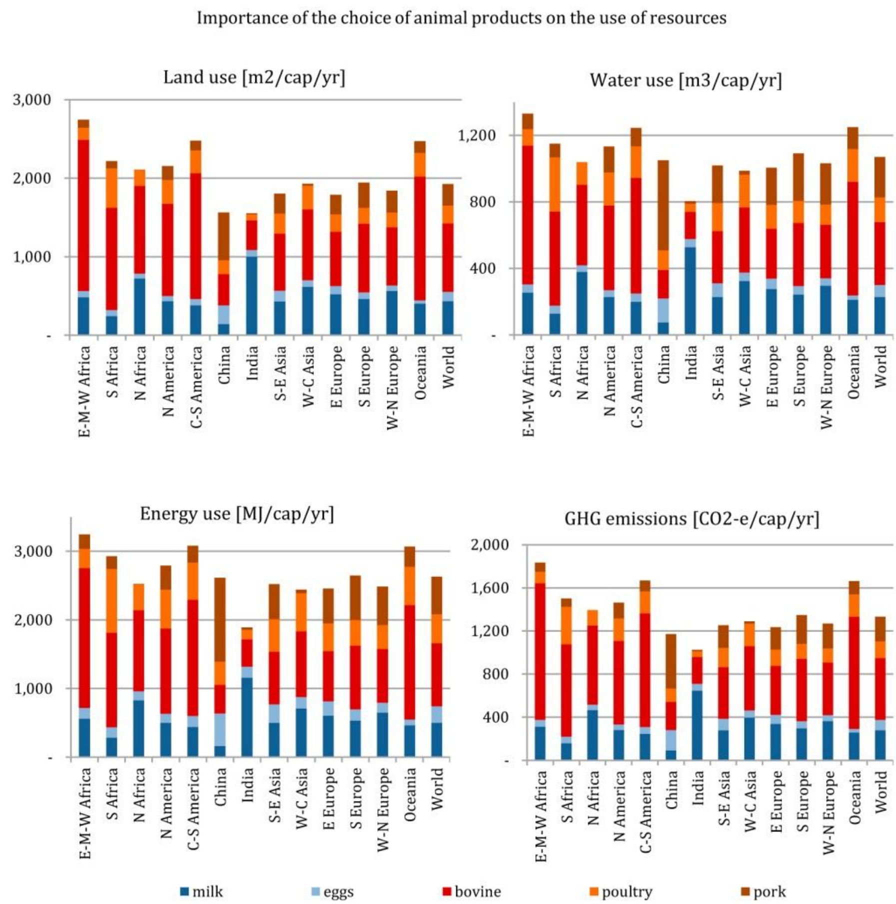

Figure 6.5 Use of resources for the consumption of 60gr protein/cap/day with the differences of regional food composition of figure 6.4.

It is widely known that diets with large consumption of meat require a lot of resources. However, one interesting finding of figure 6.5 is that the animal products food pattern of E-M-W Africa and C-S America uses more resources than “western” regions like N America and W-N Europe. Also, the use of resources (specially of land use and GHG emissions) between India and China is almost the same, even though the consumption of meat in India is very low. These two findings can be explained with the efficiency of the animal products (table 6.1). E-M-W Africa and C-S America have the largest share of beef in their food composition, which is the animal product requiring the largest amount of resources per amount of food produced. China and India show very different composition of their animal products consumption: 60% of the protein consumption in China is meat and in India only 10% and the rest are dairy products. The largest share of the meat consumption in China is pork and poultry, also eggs consumption account to 15% of the protein consumption. The production of one protein of pork, poultry and eggs requires similar amount or in some cases less amount of resources than the production of one protein of milk (table 6.1). As a result, the animal protein consumption of India with almost no meat and only milk, does not result in lower use of resources in comparison with a consumption of large amount of meat like in China. Thus, the type of meat makes a big difference.

6.5 Discussion

In this study, we have used data from several sources and we have made several assumptions which should be discussed to understand our results in perspective. We discuss four general points:

1. The data to calculate the use of resources was gathered from one production system (table 6.1). We assumed that this production system was used in all regions. By doing this, we are not calculating the real use of resources of the region, what some call “footprint”. But, we are able to compare only the differences in diets, and not the differences of production systems, which is the goal of this paper.

2. The production system that we chose is high resource intensive for bovine meat which highly influences the use of resources for diets with high beef consumption. However, in general, all studies in the literature show that beef is the type of meat requiring most resource. This is due to the physiology of the

animals: ruminants animals (cattle) are much lower efficient in producing a kilogram of food protein than non-ruminants animals (chicken and pig). Therefore, the absolute values of table 6.1 might be different for other production systems, but the relation among the type of animal food products is in general the same. For example, the values of other study by Elferink (2009, pag 68) show similar relation among the type of animal products. So, the general differences on the use of resources among the regions that we have shown can also be expected for other production systems.

3. The aim of this study is to do a global analysis. We used global average data of production systems when it was available. For the production system of animal products, a global average was available only for the use of water, for the other resources we used a European production system. The use of water is highly dependent on the climate and it largely differs from country to country (Mekonnen & Hoekstra, 2011a). The European production systems are relative intensive systems with high yields and high energy inputs in comparison with other systems of the world. As a result, these systems are land efficient. So our results of land use are an underestimation in comparison with the global average, and for the use of energy and GHG emissions are an overestimation in comparison with the global average.

4. We used food supply data (FAO, 2013d) for the diets of each region. These values are not the actual food consumption of the population, since they include food losses. But, they are an indication of the consumption pattern and they are useful for comparison among countries (Gerbens-Leenes et al., 2010). Also, since we discuss the use of resources for the production of food, then the resources needed to produce the food losses should also be included.

Thus, considering these four assumptions, our results should be interpreted qualitatively and not quantitatively. The differences among regions and the general trends in time are the aim of this study and not the exact values of our calculations.

Most studies of future food security and use of resources use the nutrition transition theory for assessing future dietary changes: change from staple food to sugars, vegetable oils and animal products. However, this trend is too rough to assess the impact of dietary changes on the use of resources because of the large differences among the food categories and food items discussed in this paper (table 6.1). For example, the differences in resource use among staple crops are large as well as the differences among the type of animal products. As a result, the composition of the diet has a strong impact on the use of resources. So, it is essential to differentiate among these food items to assess future use of resources. Kastner et al. (2012) calculated the land requirement for food for all regions. They did not differentiate among the type of animal products but they assumed that the production of a calorie of any animal product requires the same amount of land. We have shown that the present regional differences in the type of animal products consumption can result in almost twice use of resources for the same protein consumption (E-M-W Africa VS India). So, the results of Kastner et al. (2012) could be an underestimation depending on the type of animal products consumption of the region.

The present discussion in the literature on the future sustainability of the global food system focuses on the strong impact of dietary changes in transition countries towards western consumption patterns. First, we have shown that there is not one “Western food pattern”. The regions commonly called as “western” show different food patterns, e.g. N America and W-N Europe show different food composition. Second, we have shown that developing regions have changed to affluent consumption (e.g. increased livestock products) but they have not followed the exact western pattern but their own food pattern. Assuming that this trend remains, the impact on the use of resources of some developing regions could be larger than the use of resources of the western countries. For example, the food pattern of animal products of E-M-W Africa and S-C America requires more resources than the food pattern of N America and W-C Europe. Also, vegetarian diets which are commonly considered as low resource intensive could use similar or more resources than diets with large amount of meat. For example, the animal products food pattern of China and India requires similar amount of land even though in China 60% of the animal product’s protein intake is meat and in India only 10% and the rest are dairy products.

These differences in resource use for regional differences in animal products consumption are due to the differences in resource efficiencies of the food items. Beef is the meat requiring more resources per protein produced, as most of the literature has shown. So, E-M-W Africa and S-C America, which have the highest relative consumption of beef, result with the highest use of resources. Also, the production of one protein of pork or chicken is relatively the same as the production of one protein of milk. So, vegetarian diets with large consumption of dairy products do not necessarily require less resources than diets with large consumption of meat like chicken or pork.

The analysis done in this study shows that large reduction of resource use for food can be obtained through changing from beef to pork or poultry consumption. In some cases, resource use can be halved. But in several regions in the world a change from beef to pork will not be a socially acceptable option due to cultural and religious traditions.

Appendix 6

The 13 Regions used in this paper and their countries

1.- **E-M-W Africa:** Eastern, Middle and Western Africa.
Countries: Angola, Benin, Burkina Faso, Burundi, Cabo Verde, Cameroon, C. African Rep., Chad, Comoros, Congo, Côte d'Ivoire, Djibouti, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Niger, Nigeria, Rwanda, Senegal, Seychelles , Sierra Leone, Togo, Uganda, U. Rep. of Tanzania, Zambia and Zimbabwe.

2.- **S Africa:** South Africa.
Countries: Botswana, Lesotho, Namibia, South Africa and Swaziland.

3.- **N Africa:** North Africa.
Countries: Algeria, Egypt, Libya, Morocco, Sudan and Tunisia

4.- **N America:** North America
Countries: Bermuda, Canada and United States of America

5.- **C-S America:** Central and South America, and the Caribbean
Countries: Antigua & Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dom. Rep., Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, St Kitts & Nevis, St Lucia, St Vincent & the Grenadines, Suriname, Trinidad and Tobago, Uruguay and Venezuela.

6.- **China**

7.- **India**

8.- **S-E Asia:** Southern, Eastern and Southeast Asia

Countries: Bangladesh, Brunei Darussalam, Cambodia, Dem. Rep. Korea, Indonesia, Iran, Japan, Lao, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Rep. Korea, Sri Lanka, Thailand, Timor-Leste and Vietnam.

9.- **W-C Asia:** Western and Central Asia
Countries: Armenia, Azerbaijan, Cyprus, Georgia, Israel, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Lebanon, Palestina, Saudi Arabia, Syrian A. Rep, Tajikistan, Turkey, Turkmenistan, United Arab Emirates, Uzbekistan and Yemen.

10.-**E Europe:** Eastern Europe
Countries: Belarus, Bulgaria, Czechoslovakia (1960), Czech Rep. (2010), Hungary, Poland, Rep. of Moldova, Romania, USSR (1960), Russian Federation (2010), Slovakia and Ukraine.

11.- **S Europe:** Southern Europe
Countries: Albania, Bosnia & Herzegovina, Croatia, Greece, Italy, Malta, Portugal, Slovenia, Spain, Yugoslav SFR (1960) and Rep. of Macedonia (2010).

12.- **W-N Europe:** Western and Northern Europe
Countries: Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Sweden, Switzerland and United Kingdom.

13.- **Oceania**
Countries: Australia, Fiji, French Polynesia, Kiribati, New Caledonia, New Zealand, Samoa, Solomon Islands and Vanuatu.